Effects of Training on the Mechanical Efficiency in Bicycle Ergometer Exercise*

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ABSTRACT

The subject participated in 5-minutes of constant-load exercise performed on a Monark bicycle ergometer (900kgm/min) five days a week for nine consecutive weeks. During this period, there was about 5 percent increase in mechanical efficiency. Furthermore there was no decrease in mechanical efficiency after a detraining period of 79 days. On the other hand, the electromyograms of the upper limb decreased remarkably in voltage as a result of training. Considering this improvement in mechanical efficiency as evidenced by the electromyograms, it is concluded that repetition of a given exercise, namely training, creates more concentrated activity within the prime muscles employed in the performance of the exercise and inhibits the activities of the muscles of lesser importance.

Key-Words: Mechanical Efficiency—Electromyograms—O_2 Requirement—Bicycle Ergometer—Training.

INTRODUCTION

Previous studies (6, 9) have shown that the amount of oxygen consumption including recovery oxygen intake during a given submaximal exercise decreases due to the regular physical conditioning or training. This result has been attributed to improvement in mechanical efficiency (2, 6). Generally speaking, efficiency is a ratio of work done to amount of energy used. Although many reports have appeared in the lierature on the mechanical efficiency during various activities such as walking, climbing, runing, cycling and swimming etc. (1, 2, 3, 5, 7, 8, 10, 14, 16, 18), there have been few experimental studies dealing directly with the effect of training on the improvement in mechanical efficiency (9, 17). Robinson and Harmon (1941) reported an 8 % increase in mechanical efficiency in grade walking after running training for 11 weeks. The purpose of the present study was to determine the effect of training with a bicycle ergometer per se on the mechanical efficiency in bicycle ergometer exercise.

METHOD AND PROCEDURES

The subject was one healthy-male volunteer of 40 years of age. His physical

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characteristics and $\dot{V}O_2max$ values are shown in Table 1. He taught physical education at a senior high school, was a competitive gymnastics athlete in his college days, and had not experienced the bicycle ergometer exercise, prior to this experiment. He performed five minutes exercise of constant load (900kgm/min) on a Monark bicycle ergometer once a day. Training frequency was five days a week for nine consecutive weeks.

After 30 minutes rest on a chair, the subject performed the exercise keeping time to a metronome at 60 rpm. After the exercise, the subject rested on a chair placed close to the bicycle ergometer for 40 minutes. Pedal revolutions were counted during each minute by use of an electrogoniometer attached to the left knee joint of the subject. The frictional force was measured accurately with the strain guages. These procedures permitted caluculation of the amount of work done. The total amount of work performed was between 4483 kgm at a minimum and 4679 kgm at a maximum.

Oxygen intake was measured throughout the rest period, during the 5-minutes of exercise and for a 40-minute recovery period. Expired gas was collected by Douglas bags. Gas volume was determined by a wet gas meter. Samples of expired gas were analyzed with a Scholander microgasanalyzer. Basal oxygen intake was determined as the oxygen consumption for 15 min, from 25 to 40 min of recovery. Mechanical efficiency was calculated from the formula :

$$\text{Mechanical efficiency} = \frac{\text{Mechanical work performed} \times 100}{(\text{Total} - \text{Basal oxygen intake}) \times 5.1 \times 427}$$

where 5.1 is the calorie coefficient for oxygen and 427 is the factor for converting kcal/min to kgm/min (15). Heart rate was calculated from ECG chest leads.

As the activities of the muscles in cycling are approximately symmetrical, electromyograms were recorded on the left side of the body only. Pure silver disc surface electrodes were attached to the skin of the arms, legs and trunk. The muscles examined were as follows : m. extensor carpi ulnaris, m. flexor carpi radialis, m. triceps brachii, m. biceps brachii, m. erector spinae, m. trapezius, m. rectus abdominis, m. biceps femoris, m. gastrocnemius and m. tibialis anterior. The electromyograms were recorded under the constant condition throughout all tests : the EMG channel, the voltage gain, the electrodes and their respective positions on the examined muscles were all kept constant. Electrode positions were marked with indelible paint.

Table 1 Physical characteristics and $\dot{V}O_2max$ per and post training

	Height (cm)	Weight (kg)	$\dot{V}O_2max$ (l)	$\dot{V}O_2max$ (ml/kg)
Pre-training	160.0	56.0	2.77	49.5
Post-training	160.0	55.5	2.84	51.2
			Δ0.07 (+2.5%)	Δ1.7 (+3.5%)

The $\dot{V}o_2$ max was determined utilizing the treadmill before and after training. A constant slope of 8.6 % was used with a gradually increasing speed until the subject could no longer continue during 5-6 minutes.

RESULTS

There were no remarkable changes in $\dot{V}o_2$ max before and after training (Table 1). It is important to note that the subject performed the required work on all tests, i.e., there was no decrement in the rate of work or the total amount of work done. The oxygen intake determined at the beginning of the training (4th day) represented 81 percent of the subject's $\dot{V}o_2$max and at the end of the training (44th day), 68 percent. Figure 1 shows the effect of training on oxygen consumption. It can be seen that, for the same exercise, the amount of oxygen used at the beginning of training was 11.7 liters, and, at the end of training, 9.2 liters. This decrement of 2.5 liters was due to both a decreased oxygen intake while exercising (1.2 liters) and a smaller oxygen debt (1.3 liters). Furthermore the oxygen requirement, oxygen intake and oxygen debt at the end of training were about the same after detraining of 79 days.

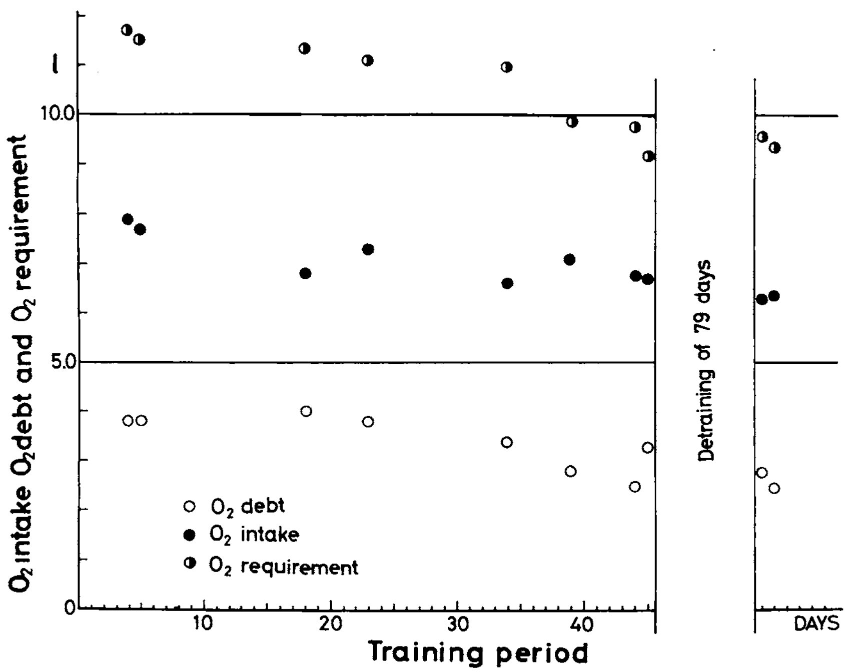

Figure 1 Changes in oxygen consumption during training and after detraining

It can be seen that there was gradual increase in mechanical efficiency from 17.8 percent at the beginning of training to 19.6 percent on 24th day and a more abrupt increase in efficiency from the 35th day to the end of training, 22.7 percent. Mechanical efficiency was improved by 4.9 percent as a result of training. Furthermore, there was no

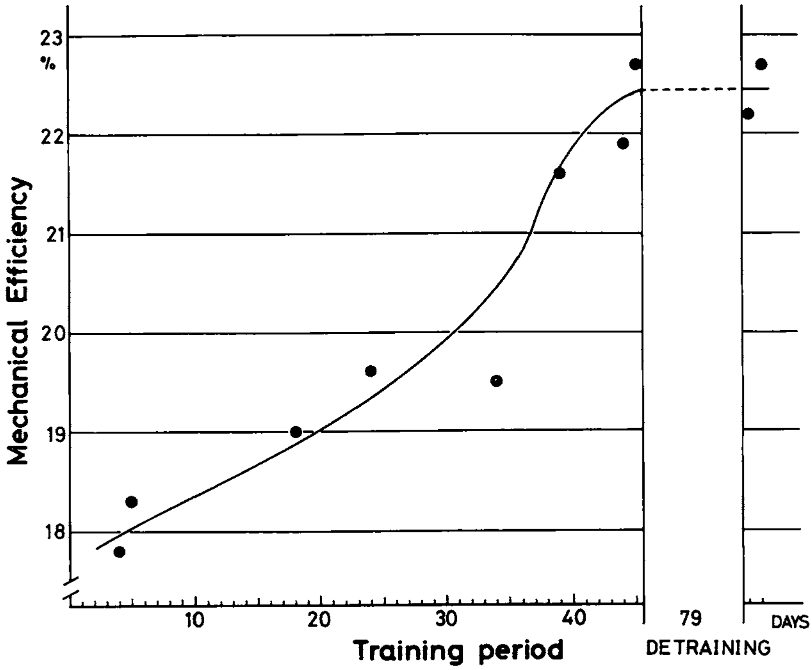

Figure 2 Changes in mechanical efficiency during training and after detraining

decrease in mechanical efficiency after detraining of 79 days, 22.5 percent (Figure 2).

The electromyograms of all muscles examined increased in electrical discharge uniformly with time during the 5 minutes of constant-load exercise (Figure 3). Following the training period, the electrical discharges of the upper limb decreased remarkably in

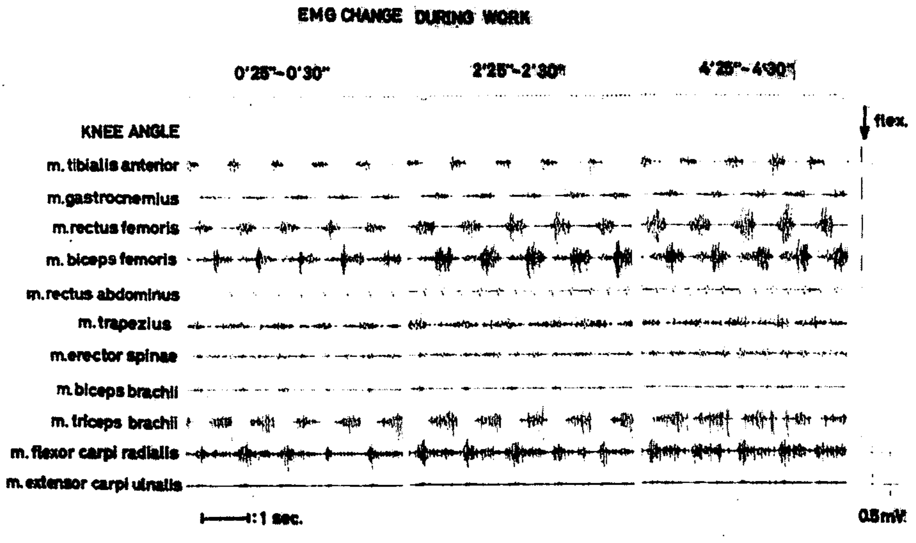

Figure 3 EMG changes during 5-minutes work (lst day's of training)

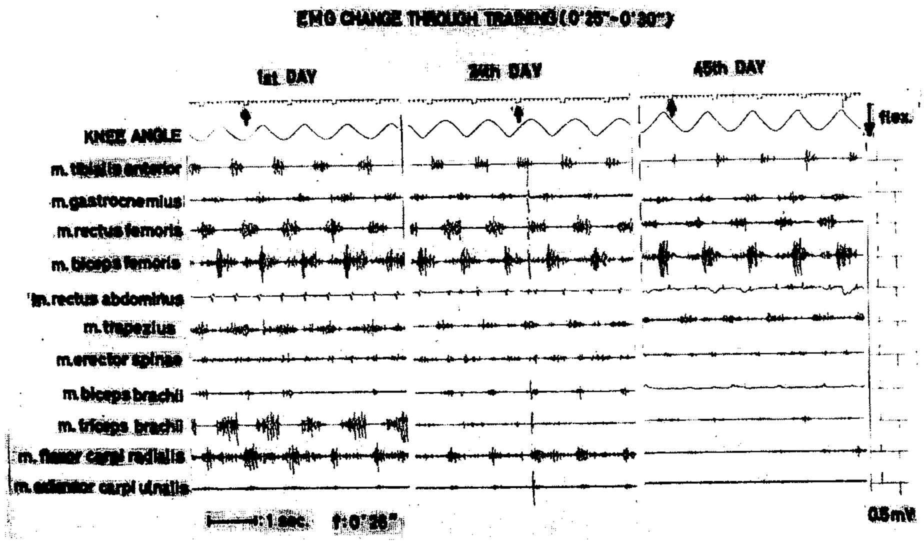

Figure 4 EMG changes just after the start of work through training

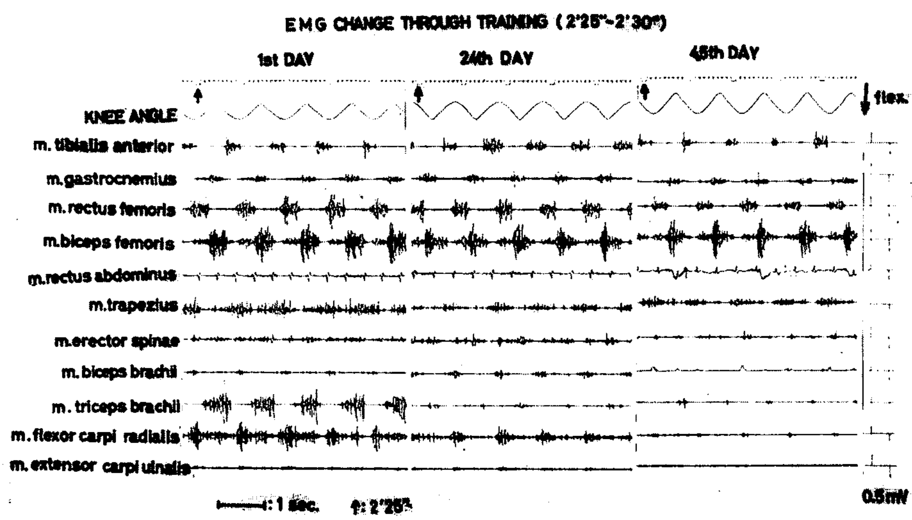

Figure 5 EMG changes in the middle of work through training

voltage in millivolt (mV) soon after the initiation of the exercise. In m. triceps brachii, those of lst, 24th and 45th day of training were 1.0 mV, 0.3 mV and 0.2 mV, respectively. In m. flexor carpi radialis they were 1.0 mV, 0.5 mV and 0.1 mV (Figure4). In the middle of the exercises, the same trend was evident (Figure 5). In the later stages of the exercise session, the electrical discharges of the lower limb decreased gradually in voltage as a result of training. There was also an apparent decrease in the electrical activity in the upper limb. In m. rectus femoris those of lst, 24th and 45th day of training were 0.9 mV, 0.5 mV and 0.3 mV, respectively. In m. tibialis anterior they were 0.6 mV, 0.3 mV and 0.3 mV (Figure 6).

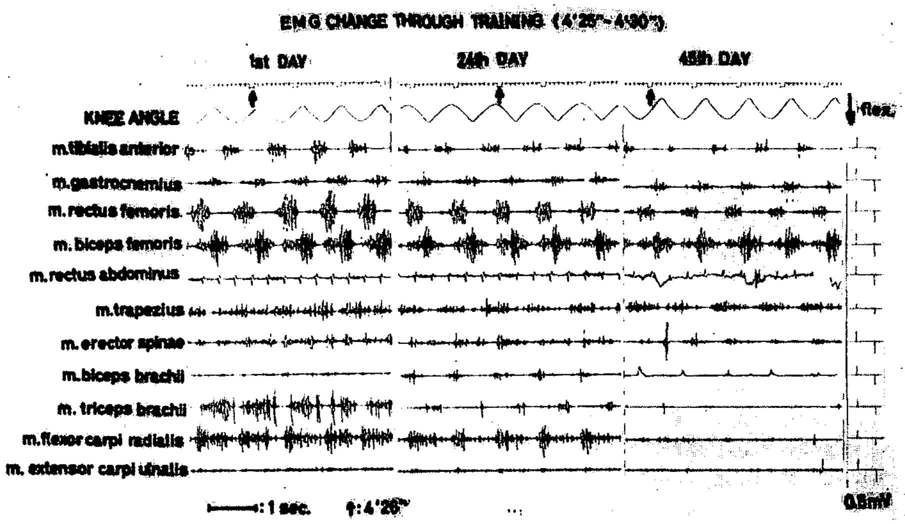

Figure 6　EMG changes just before the end of work through training

DISCUSSION

The bicycle ergometer was used because the amount of work performed during the standard exercise could be easily measured and possible changes in body weight resulting from training would not influence the calculation of work output since the body weight was supported (4, 8, 12).

As a result of training there was an improvement in mechanical efficiency of about 5 percent from the beginning of training to the end of training. Further, the mechanical efficiency was remained relatively the same after detraining. These values of mechanical efficiency during cycling obtained in this subject are approximately equal to those reported previously by P. −O. Åstrand (1952), I. Åstrand (1960) and Christensen et al. (1960). The value of 17.8 percent at the beginning of training is in the lower range of these values and that of 22.7 percent obtained as a result of training is in the upper range.

In the present study, the electromyograms were recorded under constant conditions in all tests, i.e., the EMG channel, the voltage gain, the electrodes and their positions were constant as suggested by Lippold et al. (1960). Considering the improvement in mechanical efficiency from the electromyograms of the whole body, we can find two trends during training. One is the very noticeable decreasing trend of the electrical discharges in the upper limb, the other is a more gradual decrease in the electrical discharges in the lower limb. These findings are in accord with the difference in the electromyogram pattern obtained on a top swimmer compared to a less successful swimmer of a university swimming club as reported previously by Ikai et al. (1964).

In summary, we have found that the subject had to use the muscles of the upper limb in the pedaling motion at the beginning of the training but gradually the lower limb played the exclusive role in pedaling without the use of the upper limb as a result of the training. In other words, it was concluded that repetition of a given exercise namely training concentrates the muscular activity in those muscles primarily used for the performance of the exercise and inhibits the activity of the muscles of lesser importance. It is suggested that this resulted in a decrease in the energy used to perform the standard ergometer exercise so that the mechanical efficiency was improved.

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